Time resolved recording of arc spot formation on cold cathodes

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An experimental set-up is presented, which allows to investigate the interaction of a dense plasma with a cold cathode. The ignition of arc attachments is recorded by electrical measurements, high-speed photography and time resolved spectroscopy. The electrodes are prepared in different ways for reproducing fine microscopic surface structures. Pictures and measurements are shown for a polished Al-electrode.

1. Introduction

The electrodes of cold HID-lamps are heavily stressed during lamp ignition by a high voltage pulse. For a reduction of this load by an improved electrode design, a better understanding of the ignition is desired. The ignition may be decomposed into two different processes. One process is the formation of charge carriers and of a bulk plasma in the lamp volume. A broad knowledge is available concerning these processes. The other process is the establishment of an electron emission at the cathode, which is sufficiently high to transfer an arc current. The understanding of this process resulting in the formation of an arc spot is rather incomplete. If the arc is extinguished immediately after ignition the electrode surface shows the formation of craters by melting and vaporization of the electrode material [1]. One explanation for the emission of electrons is that microscopic structures on the electrode surface are heated by the high energy of the incoming ions. To investigate the influence of the surface structure on the ignition of arc spots independently of the processes in the discharge volume, a special experimental set-up was developed [1]. An arc ignited between two electrodes in a pure argon atmosphere (0.106 MPa) is blown magnetically against a third so-called commutation electrode CE. The ignition is recorded by electrical measurements, high-speed photography and time resolved spectroscopy. The electrodes are prepared in different ways for reproducing fine microscopic surface structures. First measurements are made with polished electrodes of copper, aluminium, graphite, palladium and tungsten. After that, electrodes of tungsten and palladium were prepared with pulverized tungsten/ palladium. For comparison electrodes of palladium were annealed at temperatures of 1273K after polishing to produce a cleaner surface.

2. Experimental set-up

The experimental set-up shown in Fig.1 consists of a pair of horn electrodes, an anode (A) and a cathode (C) between which an arc is ignited by a high voltage breakdown. After the ignition the arc is blown magnetically against a diaphragm (D) which is positioned horizontally above the horn electrodes. The third electrode CE ($\varnothing$ = 2mm) is arranged perpendicularly to the arc axis in the center of the diaphragm aperture. The whole discharge arrangement is enclosed in a vacuum tight chamber equipped with windows for optical observation. The electrical set-up can be divided into four circuits, the ignition circuit (S1, R_3, R_4 and C_1, charged onto the voltage U_1 = 1.8kV), the arc circuit (current source I_0, R_1, D_1 and R_4), the circuit of commutation (CE, D_3) and a circuit for acceleration of commutation (S2, C_2 and R_2). By closing the switch S1, the arc between the horn electrodes is brought into operation with a constant current of I_0 = 25A. By the resistance R_4 the cathode potential is raised up to 250V, so that CE is negatively biased against the arc plasma. By applying a magnetic field (B) in addition to the thermal lift, the plasma is blown against the diaphragm and the CE. After a time of a few hundred μs the current of the arc is taken over by the new cathode. This is marked by a steep current increase through the CE. The experiment is stopped by triggering the thyristor T_1. To record the initiation and the development of arc spots by high-speed photography, it is necessary to produce a trigger signal before a current through the CE can be measured. As shown in Fig.1 an optical trigger signal is generated by using a laser diode (LD), whose wavelength is adjusted to a strong atomic line of the filling gas (in case of argon a line at 811.531 nm). If the arc plasma passes the diaphragm the radiation of the laser diode is partly absorbed. This is detected by a sensitive photodiode PD. The signal of the PD is used to generate time delayed trigger signals for all cameras and to trigger the switch S2 which connects the negative pin of C_2 (charged onto a voltage U_2) with CE. By applying the voltage U_2 the commutation process is more accelerated and timed.

3. Measurements

The arc current (I_B) and the current through the CE (I_c) are recorded by current probes Cp1 and Cp2 (shown in Fig.1). Pictures are taken with a high-speed CCD-camera (PROXITRONIC) which allows exposure times down to 5 ns and also with a streak camera (Hamamatsu) which makes it possible to record the development of arc spots on the CE. Generally the Proxitronic is triggered by the current in-

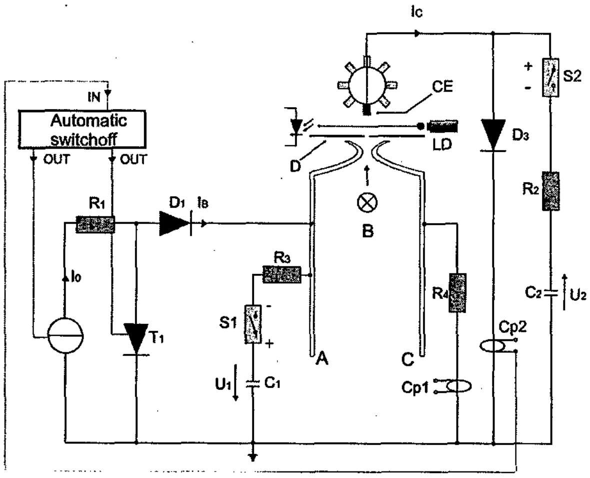

Figure 1: Experimental set-up

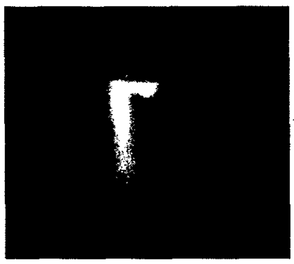

Figure 2: Proxitronic image: ignition on polished Al; $U_2 = 600$V, plasma channel between the bulk plasma and a luminous layer in front of the CE; $T_{delay} =$ 300ns.

crease of I_c and the streak camera by the signal of the laserdiode. In some cases (for Cu, Al, Pd and C) the trigger time for the Proxitronic is delayed in addition by a digital delay generator to examine the arc attachment at different times during the increase of I_c. These series of pictures can only give a overview about the development of arc attachment, because only one picture can be taken per ignition. Spectroscopic measurements are taken with different spectral resolutions with a intensified CCD-camera (Dicam Pro, PCO), operated in double shutter mode. This mode allows to get two separate pictures with a minimum of time delay of 1 μs between them showing as in Fig.3 changes of the spectrum with time. Measurements are made at different voltages U_2 from 0V up to 950V. Furthermore SEM images are taken of the electrodes before and after a number of ignitions. In some cases (for Al and Pd) only one ignition is executed, where the current through the CE is switched off after 700ns. The given examples in Fig.2 and 3 are characteristic for the two different operating modes: $U_2 = 0$V and $U_2 > 300$V.

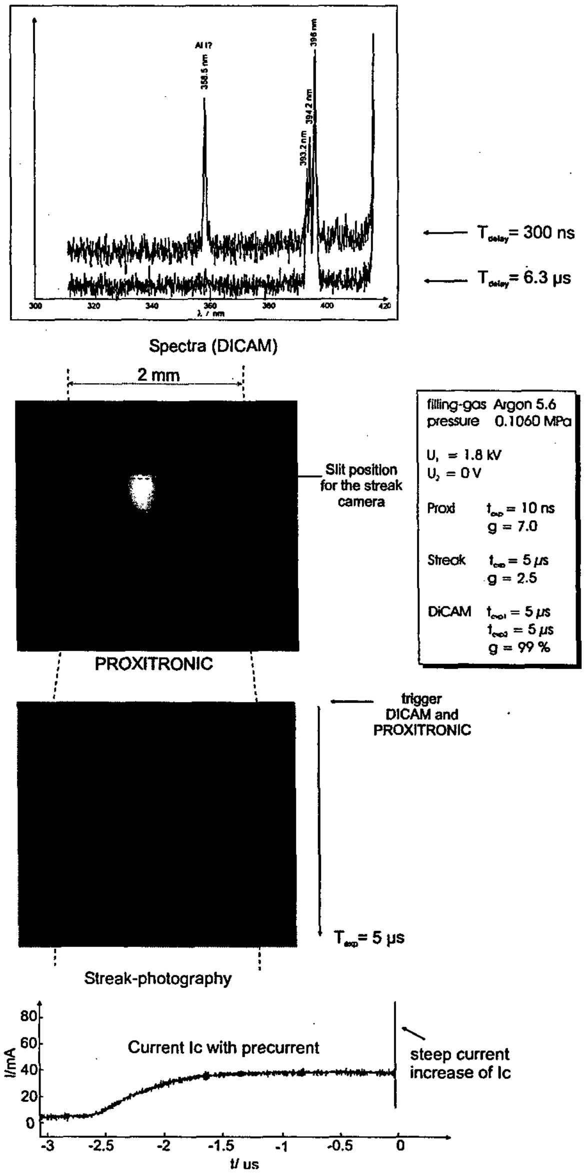

Figure 3: Ignition on polished Al; $U_2 = 0$V, recorded with high-speed cameras DICAM and PROXITRONIC, streak camera and current probe.

4. Acknowledgements

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5. References

[1] J. Schein, M. Schumann, D.Nandelstädt, J.Mentel "Investigations of the ignition of arc spots on cold cathodes in a noble gas atmosphere", IEEE Trans. Plasma Sci., vol 25, pp. 897-904, 1997.